GREATER HOUSTON FLOOD MITIGATION CONSORTIUM

Research Paper 1: Detention & Drainage Regulations

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Definitions and Abbreviations

AEP	Annual Exceedance Probability - the probability of a storm event exceeding a particular flood level in one year.
Detention	Collecting and storing stormwater, and releasing lesser amounts.
Detention volume	The total amount of water detained, measured in acre-feet / acre.
HCFCD	Harris County Flood Control District
HEC-HMS	Hydrologic Modeling System designed to simulate hydrologic conditions and processes of a watershed.
HEC-RAS	Hydraulics modeling
Hydrology	Study related to rainfall as related to geography and geology.
Hydraulics	Study related to flow of water through rivers, channels, or drainage networks.
NOAA	National Oceanic and Atmospheric Administration within the U.S. Department of Commerce
Peak flowrate	Maximum volume of water passing through per unit of time, measured in cubic feet per second (cfs).
Rational Method	Estimation technique for design discharge from a small watershed.
Retention	Collecting and storing stormwater indefinitely until it evaporates or infiltrates the ground
Runoff rate	The rate at which water flows over ground surface. Higher ground imperviousness means greater the runoff, and leads to more water in the drainage systems.

EXECUTIVE SUMMARY

The Houston region depends greatly on detention regulations that ensure new development does not create an adverse downstream effect. Current detention regulations were adopted starting in the 1980s, and credit is due to both the city and HCFCD for working to dramatically decrease the impact of new development on flooding. Generally, HCFCD rules govern large development sites and unincorporated areas while city rules govern smaller developments within their boundaries.

Today, the understanding of rainfall and flooding and the tools available to analyze the impact of flooding have significantly improved, which provides an opportunity to create more effective and more targeted regulations.

This report summarizes the current regulations within the City of Houston and applicable regulations from Harris County Flood Control District (HCFCD) and identifies areas where current regional detention regulations are allowing some new development to increase downstream flooding. Three key findings include:

- The regulations overestimate the runoff from some undeveloped land, thereby underestimating the detention required to maintain current conditions.

- The regulations use "one-size-fits-all" formulas for allowable runoff and required detention volume that do not reflect the variation in soils and natural ecosystems across the county.

- The regulations only address maximum flow rate, not total runoff volume, which means that the cumulative effect of multiple developments can still increase flood levels, that downstream flooding can last longer, and that multi-day events can have a greater impact even if current requirements are met.

While there is not enough information to quantify the degree to which current regulations may fall short of mitigating flooding, there is sufficient data to indicate that, in some cases, they do allow new development to increase downstream flooding, and that requires further investigation.

Additional research and a process for updating regulations, but not specific new regulations, are recommended in this document. The findings from this report outline a multi-step process to implement more sophisticated regulations including:

- Increase the default minimum detention requirements set by the City of Houston and HCFCD for lots of all sizes to cover the variation in pre-development conditions. This reflects a change in approach to the minimum value. Instead of representing the typical runoff from an undeveloped site, it would represent the high end of the range of expected runoff.

- Allow any developer or property owner with a lot of any size to provide less than the default minimum requirement if they provide an engineering study, based on field observations, that quantifies pre-development runoff. Where current regulations are adequate, this would result in the same detention that is required today. On most sites it would require less detention than the default value. This might be the same that is required today, or may be more. In every case, it would more accurately reflect the pre-development conditions.

- Install gages downstream of a variety of undeveloped sites across the Houston region to collect data on runoff that could be used to develop more precise watershed specific regulations.

- Commission engineering studies on the undeveloped portions of all major watersheds in Harris County to determine appropriate detention parameters, taking into account cumulative effects across entire watersheds.

- Based on these studies, set specific regulations for watersheds or parts of watersheds. These regulations could be coordinated across multiple jurisdictions in the watershed.

- Require the evaluation of cumulative effects across entire watersheds.

- Require the evaluation of a variety of storms, including 3-, 5-, or 7-day events in addition to the 1-day and less events required today.

INTRODUCTION

Houston and Harris County face a substantial challenge in addressing existing flooding issues. Tens of thousands of homes are at risk of flooding under current conditions, and even the billions of dollars in new flood mitigation infrastructure that is currently being planned will not address all the needs. At the same time, Houston and Harris County face a parallel challenge of mitigating the impacts of new development on flooding.

Since the mid-1980s, it has been the adopted policy of both the City of Houston and Harris County that new developments should mitigate their own impacts on flooding. In principle, the policy was that new development should not be allowed to increase flooding upstream or downstream (i.e. "No Adverse Impacts" or NAI).

The most often used tool for mitigating development impacts is detention. Detention ponds collect and hold stormwater runoff (rain water that flows on the ground surface) from streets and buildings and release it slowly, reducing the rate of flow downstream. To achieve a NAI policy, Harris County, the City of Houston, and the HCFCD have all adopted detention regulations with a goal that the post-development runoff does not exceed the pre-development peak runoff flow rate. Other cities have adopted similar requirements, and while this document focuses on Houston, its conclusions are likely relevant in other jurisdictions as well.

In principle, these detention regulations were intended to achieve the goal of mitigating impacts from new development and achieve the NAI policy.

This document explains:

-The effects of development on the hydrological behavior of the landscape and how development affects runoff and flooding;

-What current regulations do to mitigate these changes; and

-What current regulations do not address

The researchers of the Greater Houston Flood Mitigation Consortium agree there are three issues with the current HCFCD regulations as adopted by the City of Houston and the regulations for larger sites, which are adopted by the city:

1) The regulations overestimate the runoff from some undeveloped land, thereby underestimating the detention required to maintain current conditions.

2) The regulations use "one-size-fits-all" drainage numbers that do not reflect the variation in soils and natural ecosystems across the county.

Detention Pond in Development

3) The regulations only address flow rate, not total runoff volume, which means that the cumulative effect of multiple developments can still increase flood levels, that downstream flooding can last longer and multi-day events can have a greater impact even if current requirements are met.

These impacts are particularly significant for new development in areas that were previously natural and agricultural, though the effect varies greatly based on the existing soils, vegetation, and type of agricultural use. This is critical because large parts of watersheds are currently undeveloped, and many of the county's residents live downstream of these areas.

In many cases, the current regulations are adequate to ensure NAI. Undeveloped conditions vary widely, so the detention required varies considerably. In some cases, the current default detention factors are too large; in others they are too small. Furthermore, detention for larger sites is based on hydrological modeling, which accounts for differences in site conditions, but not the default standard values of maximum runoff, minimum volume, and standard runoff curves used for smaller sites.

There is sufficient data to indicate that on some sites the current regulations dramatically underestimate the detention required to mitigate development impacts. There is also enough data to conclude that the current regulations are in some cases not sufficient, but not enough data to conclude what would be required to fully mitigate impacts. Thus, additional research and a process for updating regulations, but not specific new regulations, are recommended in this document.

Mitigating new development is a critical part of building a more resilient region,. Studying best practices adopted by other regions, determining actual runoff from undeveloped land in different watersheds, and conducting additional research into the unique conditions of the upper Texas coast

EFFECTS OF DEVELOPMENT ON LANDSCAPE, RUNOFF, AND FLOODING

can be helpful when considering more effective regulations.

Mechanics of Drainage

There are several factors that affect how much water runs off a site.

Soils.

Stormwater runoff increases as the permeability of the land decreases. Permeability of soils greatly depends on the physical characteristics of the soil; clay soils will be much less permeable than other types of soils such as sand and loam. Water not carried on the land's surface by runoff infiltrates (soaks into) and drains downward through the ground.

Land Cover.

Land cover affects the absorption rates and storage of a site and, hence, the amount of water that runs off. Different types of vegetation (e.g. large trees and prairie grasses) have different absorption rates that influence the storage potential for infiltrated water. Similarly, the above-ground biomass of plants (e.g. stems and leaves) slows the speed of water as it is intercepted by the tree canopy or travels across the soil surface, allowing more of the water to evaporate or infiltrate into the soil. A healthy, robust, and biodiverse habitat leads to a greater volume of water that is slowed down and captured, reducing the amount of stormwater that drains as surface runoff.

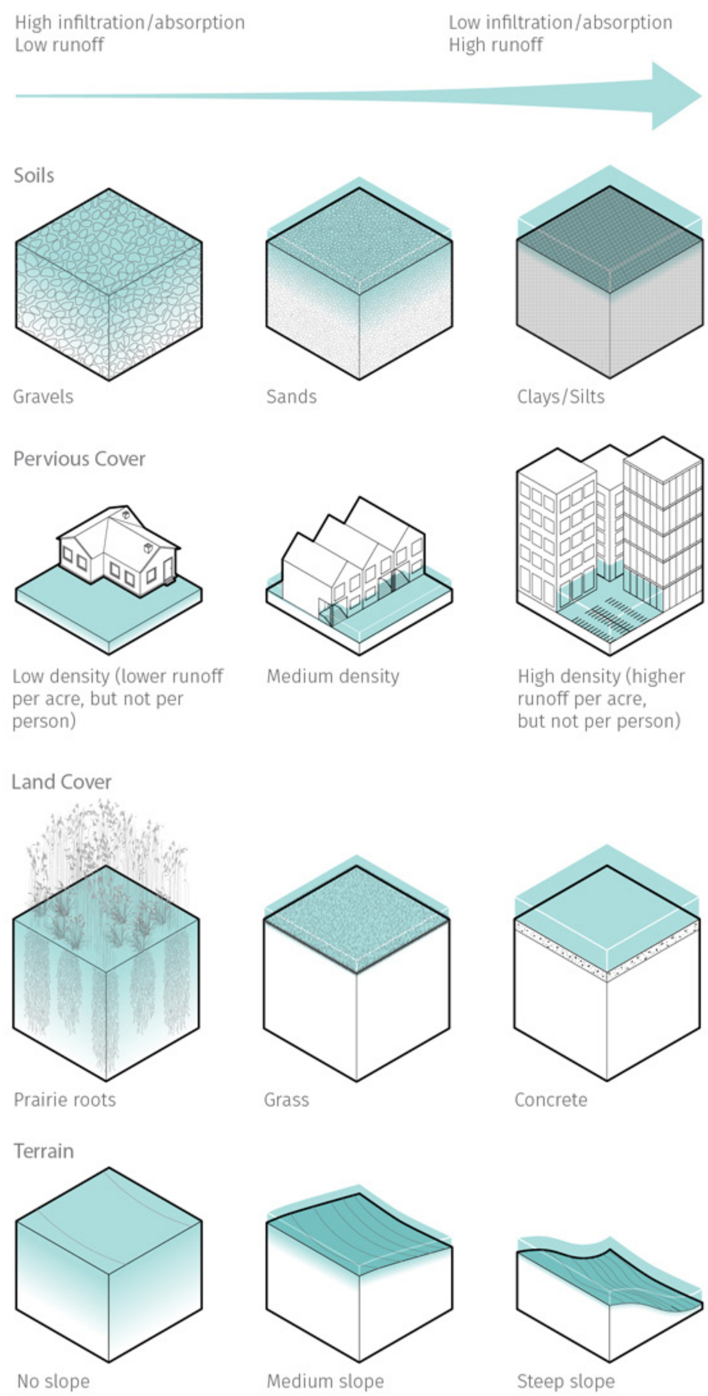
Land Use.

Land use describes the type and density of a development. Higher density development, such as multi-family housing, has greater impervious area than lower-density development, such as single-family residential, and therefore higher runoff. Impervious surfaces such as parking lots, roads, and roofs do not allow water to infiltrate into the ground while natural landscapes such as forests, wetlands, and grasslands do. Watersheds in areas with large amounts of impervious surfaces experience higher rates and volumes of stormwater runoff than those watersheds with large expanses of water-absorbing natural habitats or permeable surfaces.

Terrain.

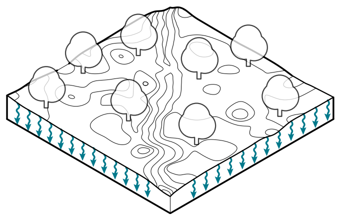
In addition to soil type and land cover, the topography of a site also has a significant effect on the timing of runoff moving over a site. The steeper the slope, the quicker water will run off the site, while flat sites with shallow depressions slow water and even store it on site. Slope can be accounted for when the modeling approach takes into account the time it takes for water to run off the site.

Water Absorption & Runoff

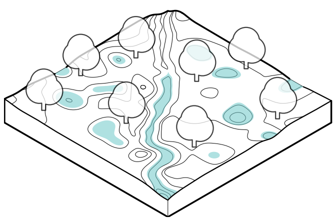


How Development Alters Flow of Water from a Site

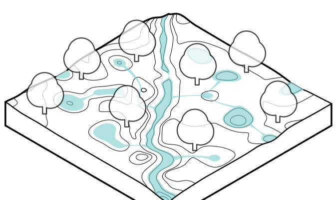
Natural



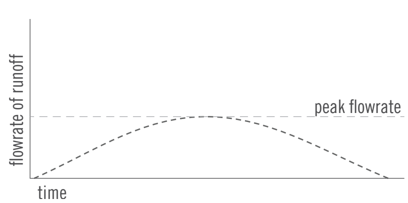
In a natural landscape, some rainwater infiltrates into the ground. This varies greatly. The sand in the northern areas of the Houston region will absorb more water than the clay in the southern areas. Vegetation matters, too; some plants, such as the native grasses of the Katy Prairie, have deeper root systems than typical landscaping; these loosen the soil and may allow more water to infiltrate soils.



In a natural landscape, some rainwater collects in depressions and undulations of the landscape. This water can stand for weeks, and often infiltrates, evaporates or is taken up by vegetation rather than running off.

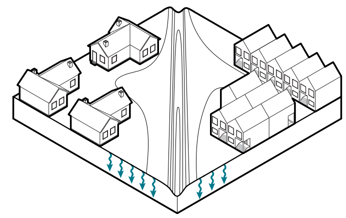


In a natural landscape, water runs off slowly. Without drainage infrastructure, much of the drainage is sheet flow across rough and dense vegetated areas. Channels are meandering and filled with natural vegetation that slows the flow of water.

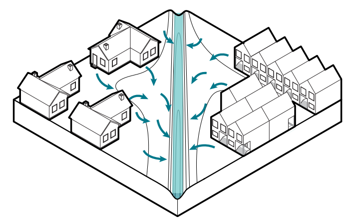


The figure above shows an example of the rate of flow of water that runs off a natural landscape; the runoff from a brief rainfall takes days to drain off a natural landscape. Since the runoff extends over a long time, the maximum rate of runoff (i.e. peak flow rate) is relatively low. Furthermore, some water never runs off – it infiltrates through the soil, is absorbed by plant root systems, or evaporates.

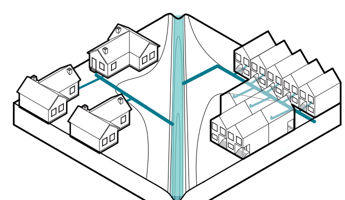
Developed



In a developed landscape, less rainwater infiltrates. Some of this is due to impervious cover; concrete, asphalt, and buildings do not absorb any water with typical construction materials. However, even unpaved areas behave differently. Man-made landscaping can have shallower root systems and more compacted soils and thus less infiltration.

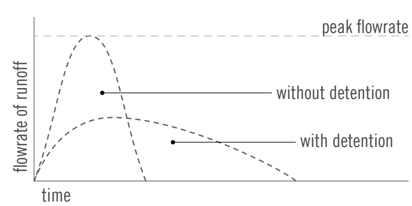


In a developed landscape, grading creates a uniform landscape that is designed to slope towards drains and ditches. This positive drainage ensures that water does not collect, but instead runs off the site and into area bayous.



In a developed landscape, water quickly makes it to a closely spaced network of ditches, drains, and storm sewers, and the runoff in that drainage infrastructure flows quickly. Channels are normally improved and cleared of natural vegetation so they can carry water away quickly, and this concentrated volume could mean higher floodwaters downstream.

Because of all these effects, the increase in runoff due to the development of a previously undeveloped site is generally much greater than the increase in runoff from the redevelopment of a previously developed and graded site, even if the increase in impervious cover is the same for both.



The figure above shows the flow of water off of a developed landscape with and without detention; the runoff from a brief rainfall drains away quickly. Since the runoff is compressed into a shorter period, the peak flow rate is much higher. Furthermore, with less infiltration and evaporation, the total volume of water running off the site is also higher.

The figure above shows the flow of water off a developed landscape with detention. If properly implemented, detention can limit flow rate to the same as pre-development conditions. However, the water still drains into the detention pond quickly, so the peak flow rate is reached more quickly after the rain starts. Because detention does not lessen the total volume running off the site, which is increased by development, the flow off the site also lasts much longer.

CURRENT REGULATIONS

Purpose of Detention Regulations

Without some form of flood mitigation, new development will increase both the amount of runoff and the rate at which that runoff enters our bayous and creeks. This results in the significant increase in flooding downstream.

Back in the 1950s and 1960s, HCFCD improved most of the natural bayous and creeks in the county and built additional drainage ditches connecting to such bayous and creeks. These improvements were to facilitate the development of lands within the county and provide some level of mitigation by increasing the carrying capacity of these waterways and prevent any increase in flooding that was to be expected from such development. This channel improvement system worked until the amount and density of new development exceeded the county's expectations. For example, the Brays Bayou channel had been improved and was expected to contain the flows up to a 1% annual exceedance probability (AEP) (also known as 100-year) storm event for an anticipated low-density developed watershed; yet by the mid-1980s new development had reached a level such that this improved channel could only handle a 10% AEP (10-year) storm event. According to data from the National Oceanic and Atmospheric Administration (NOAA) analyzed by the Houston Advanced Research Center (HARC), the Brays Bayou watershed was 94% developed as of 2010. Agricultural grazing lands, freshwater wetlands, and prairies capable of facilitating stormwater retention and infiltration were replaced by subdivisions and office parks. Natural habitats in the region adapted to high water long ago, but development can place people and structures in harm's way of that same high water.

To address this, all major local jurisdictions require detention. Within the City of Houston, smaller development is governed by City of Houston criteria. Larger developments often drain directly to bayous or flood control channels and are thus regulated by HCFCD. For consistency the city has adopted HCFCD criteria for all large developments (over 50 acres), even where the city has jurisdiction, though city limits on release rates also apply and may be more stringent.

The goal of current detention regulations is to collect and hold the runoff and release it at a rate that will not increase flooding downstream, upstream, or on adjacent properties. To achieve that goal, the release rate after development is to be no greater than the existing release rate from the site before development (though the regulations allow an increase in the overall volume of runoff.) To accomplish this, detention captures water before it leaves the site and then releases it slowly over time. The size of detention ponds is directly related to the allowable release rates; the lower the rate of release, the larger the size of the pond needs to be to mitigate the amount of runoff that new development will generate.

Detention regulations vary greatly by the size of a project. The rules for smaller projects are simpler in order to avoid unnecessary engineering work. Regardless of project size, all of the rules are trying to accomplish one fundamental goal: limiting runoff to pre-development levels. This requires the city and HCFCD to determine what pre-development runoff is. For small sites, the regulations simply dictate a runoff rate that is intended to match natural conditions. For large sites, the developer's engineers are required to calculate pre-development runoff. For small sites, the city also requires a minimum detention volume, which is intended to accommodate the design storm (a theoretical level of rainfall, generally the estimated 1% or 100-year storm, designed by the local jurisdiction as the standard for all infrastructure) within the allowable runoff. For large projects, the developer's engineers size the detention based on site-specific calculations.

Current Regulations for Large Sites

Detention Volume on Sites Over 50 Acres

For sites over 50 acres, the City of Houston uses HCFCD methods.

HCFCD limits post-development flow rate to pre-development flow rate for each of the pre-development (existing) 50%, 10%, and 1% AEP 24- hour events. It also requires that detention basins drain within 48 hours.

HCFCD uses three different methods, depending on the size and complexity of the model. All are based on calculating pre- and post- development runoff and mitigating the difference. Designers must use the higher of the values resulting from the applied method or the minimum listed in the table below. HCFCD's factors are based on area of new development, which is based on the property area, not just the area of impervious cover.

Applicable Harris County Flood Control District Detention Requirements

Project Conditions	Project Type	Available Methods			Min. Detention Req. (ac-ft/ac)
		Optional Project Routing Technique	Small Watershed Hydrograph method	Watershed Modeling Method	
50-640 acres	Roadway only	•	•		
	All		•		0.55
	Complex projects over 300 acres			•	0.45
Over 640 acres	All			•	0.45

** For new developments with limited on-site drainage improvements and impervious cover < 15%, minimum detention required is 0.35 ac-ft/ac*

The Small Watershed Hydrograph Method is based on a series of pre-calculated curves provided by HCFCD. These curves or equations provide a peak runoff based on an area and percent imperviousness for existing and proposed discharges, the existing being the maximum allowable discharge from the project. Specific site conditions are not taken into account. The Small Watershed Hydrograph Method provides a series of equations to determine a hydrograph for the project site. Direct runoff values are provided based on location in one of the three regions of Harris County and the percent imperviousness. These Site Runoff Curves can be used when only peak flows are needed and there are no alterations to FEMA floodplains. Using the direct runoff values, area, and peak discharge from the site runoff curves, a hydrograph can be developed. By looking at peak discharge at different time increments for existing and proposed conditions, the cumulative storage needed can be determined. Detention is then designed to meet this storage or the minimum listed in the table above, and the peak discharge is checked to make sure that it does not exceed existing conditions.

Another method, the Optional Project Routing Method, is a variation of the Small Watershed Hydrograph method. The site runoff curves are used to determine the existing conditions or maximum allowable peak discharge. Models or computations are used to design the detention to meet this value. When using this method, existing and proposed discharges must be checked at the detention basin outfall as well as at least three nodes downstream to make sure existing values are not exceeded and there are no downstream impacts. Designers may choose this more intensive method, as it may allow for a lower minimum required detention volume.

Watershed modeling is used for more complex or larger projects that outfall into channels. In this method, the developer submits two computer models. One represents the pre-development condition, and one represents the post-development condition. The post-development runoff rate must not exceed the pre-development rate. Thus, the pre-development model determines the allowable runoff, and the post-development model demonstrates that runoff will not exceed the pre-development rate. Existing and proposed conditions must be modeled using HEC-HMS and HEC-RAS software. Existing peak discharges and water surface elevations must not be exceeded in proposed conditions. HCFCD provides a Hydrology and Hydraulics Guidance Manual (posted at https://www.hcfcd.org/technical-manuals/technical-document-library/) for modeling using these methods.

HCFCD requires detention to be designed based on a storm no less than 24 hours in duration. Although there are several different methods used in Harris County to determine detention volumes, all methods require that existing conditions peak discharges be determined and not exceeded for the 1%, 10%, and 50% AEP design storms.

Current Regulations for Small Sites

Other than HCFCD, the City of Houston regulates the largest land area in Harris County. Thus this report focuses on its rules; however, it is important to note that many other jurisdictions in Harris County and the surrounding region also have detention regulations. The City of Houston takes an approach of using a set factor based on the amount of impervious area to determine the size of the detention pond (i.e. storage volume). The goal is for this storage volume to produce a post-project peak flow rate that is no greater than the pre-project peak flow rate, although the exact rates are not calculated.

Much of the development within the city is infill and redevelopment. The city has recently strengthened its detention regulations for redevelopment, though it should be noted that city regulations apply to natural and agricultural sites as well. Even within largely developed areas, there may be individual parcels that have never been graded or developed. In undeveloped portions of watersheds, smaller developments, like subdivisions of a few homes or smaller commercial sites, fall under small site requirements.

Detention Discharge Rates

The City of Houston limits discharge from detention into existing storm sewer lines or ditches. If the maximum pool elevation of the pond is at or below the hydraulic grade line (HGL) of the downstream system, the outlet can be sized for the full-flow capacity of the downstream system. If the maximum pool elevation is above the HGL of the downstream system, a reducer or restrictor pipe should be used and sized to release no more than 2 cubic feet per second (cfs) of runoff per acre or the proportional amount of pipe capacity allocated to the development if on a shared site. The City's manual states that 2 cfs per acre is the approximate discharge from any undeveloped tract for the 100-year storm. This is a crucial value – if the actual runoff from an undeveloped site is less than 2 cfs per acre, then detention built to meet this standard would still result in increased downstream flooding.

Detention Volume on Single Family Residential Lots

Single-family residential lots of 15,000 square feet or less do not require detention in many cases. However, when they do require detention, it is set at a standard volume of detention per acre of impervious area that resulted from new construction.

Detention for Single-Family Residential Lots

Project Conditions	Detention Requirement
Single-family residential lot with area <15,000 sq. ft. & impervious surface <65%	No detention required
Single-family residential lot with area <15,000 sq. ft. & impervious surface >65%	No detention required for first 65% of impervious surface; 0.20 acre-feet/acre after first 65%
Single-family residential projects that are platted to contain more than one lot and access to these individual lots is to be provided by a common or shared driveway	0.2 acre-feet/acre of impervious surface

Detention Volume on Sites Under 50 Acres

For sites less than 50 acres, City of Houston provides a simple formula to determine the volume of required detention. This calculation is based on a few factors:

Impervious Surface (paving, roofs, and decks) – Impervious surface means any area that has been compacted or covered such that it does not readily absorb water or does not allow water to percolate through to undisturbed soil strata. Surface materials considered impervious include, but are not limited to, bricks, pavers, concrete, asphalt, compacted oil-dirt, compacted or decomposed shale, oyster shell, gravel, or granite, and other similar materials. Surface features utilizing such materials and considered impervious include, but are not limited to, decks, foundations (whether pier and beam or slab), building roofs, parking and driveway areas, sidewalks, compacted or rolled areas, paved recreation areas, swimming pools, and other features or surfaces that are build or laid on the surface of the land and have the effect of increasing, concentration, or otherwise altering water runoff so that flows are not readily absorbed.

Disturbed Area – Disturbed area means the existing surface has been altered by, but not limited to, clearing, grubbing, demolition, grading, excavating and construction related activity (e.g. equipment staging, stockpiling of fill material and material storage areas), and construction support activities.

Detention on Sites Under 50 acres

Project Conditions	Detention Requirement
Area <1 acre & not single-family residential	0.2 acre-feet/acre of impervious surface
Area between 1 and 50 acre	0.5 acre-feet/acre of impervious surface

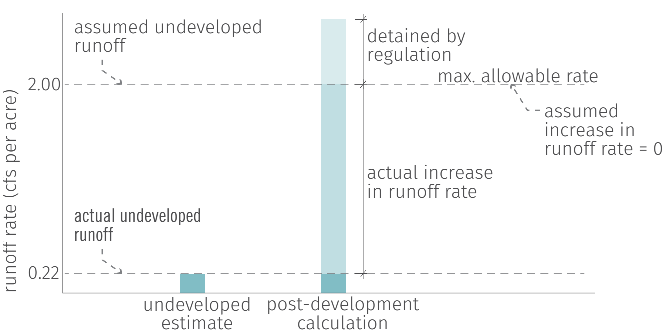
A length of storm event must be assumed when modeling runoff from storm events. When modeling is used, the City of Houston requires that:

- For design purposes, the rainfall duration for drainage areas less than 200 acres will be no less than 3 hours in duration.
- For design purposes, the rainfall duration for drainage areas more than 200 acres will be no less than 6 hours in duration.

WHAT CURRENT REGULATIONS DO NOT ADDRESS

Current regulations overestimate runoff from undeveloped sites.

All of the methods used to determine required detention – both the simpler methods for small sites and the more detailed methods for larger sites – are designed to quantify and mitigate the difference in runoff between a developed site and an undeveloped site. Thus, they must make assumptions – either in the models or in the standard runoff factors – of what runoff from an undeveloped site is. The higher the assumed runoff from an undeveloped site is, the less detention will be required, as the difference between undeveloped and developed will be less. As noted below, multiple studies indicate that both City of Houston and HCFCD methods overestimate the runoff from undeveloped sites, which means that the detention they require for new development may not fully offset the increase in runoff rate. It should be noted models are also making assumptions on the behavior of developed sites. These are likely to be more accurate than pre-development estimates since the site is designed to drain in a specific way, but how accurate these models are will also affect how well the regulations mitigate runoff.



City of Houston requirements for small and medium-sized sites, which require projects to mitigate impervious cover and not the complete developed area, do not take into account the effects of clearing, grading, and the installation of drainage systems on runoff. HCFCD methods may also underestimate these effects.

City of Houston requirements for sites less than 50 areas are based on the impervious area. If a site is developed so that 60% of the site is covered with parking lots, roof, and other impervious surfaces, with the remaining 40% being landscaping, the regulations require detention for the runoff of the 60% impervious area and do not require any detention for the 40% of the site that remains pervious.

Although HCFCD's minimum detention factors are based on the total project area, the HCFCD watershed hydrograph method, which is applicable for all sites up to 300 acres and many sites up to 640 acres and is used to determine peak flow, is also based on the increase in impervious cover. HCFCD provides a series of runoff curves, ranging from 0% impervious to 85% impervious, and with this method, the difference between the curves set the required detention: if a developed site is 60% impervious, then the developer must detain for the difference in runoff between the 0% curve (which is assumed to represent the undeveloped condition) and the 60% curve. Developed green areas are assigned an impervious value of 15%; this does not directly address the changes to soil, vegetation, and topography that affect runoff rates and may or may not offset it.

By accounting only for impervious cover, the City of Houston method assumes that replacing a natural field or forest with man-made landscaping has no effect on runoff. In many locations across much of Harris County, this is not the case. Man-made landscapes are generally well-drained. Like parking lots and building pads, lawns are graded to slope to ditches, gutters, and drains which are distributed across the entire site. If it is not absorbed by the soil, water will run off fairly quickly. Many natural landscapes, though, are poorly drained. Water collects in depressions and runs off slowly overland to the nearest natural channel, which may be thousands of feet away. Furthermore, many native plant species have much deeper root systems than the species used in landscaping, which helps the soils absorb more water.

Thus, in assuming a well-drained natural site, the City of Houston can underestimate the increase in runoff caused by development and underestimate the amount of detention required to mitigate that development. Notably, infill development and redevelopment sites are often already well-drained, so these issues do not apply in the same way to those sites. It is also not clear that the HCFCD runoff curves reflect sites that are not well drained.

Different natural and agricultural sites have very different runoff behaviors. Some are well-drained; some are not. However, these regulations do not require any evaluation of the existing condition of the site.

It is important to note that the modeling required for larger sites does require an existing condition calculation, and thus these effects should be accounted for on those projects; whether they are or not depends on what parameters the

design engineer puts in the model. Often, calculating the impacts of large sites requires engineers to create a revised pre-development model that divides drainage areas in the existing models provided by HCFCD into smaller subareas , some developed and some undeveloped, to calculate the impact of development. If that model uses the same assumptions for undeveloped sites as are used for small sites, it will have the same shortcoming that the regulations for small sites do and can also underestimate predevelopment runoff.

Notably, some other jurisdictions require modeling for smaller sites. The City of Austin requires modeling for projects larger than 100 acres, and City of San Antonio requires modeling for projects larger than 200 acres. Both require modeling when designing detention for any size of project.

Local jurisdictions have concluded that the runoff from many undeveloped sites is far lower than what the City of Houston and Harris County allow from developed sites and have adopted more stringent regulations.

Studies done for the Clear Lake Water Authority (CLWA) concluded that undeveloped peak flow rates for the 100-year event for areas within their boundaries vary between 0.1 and 0.25 cfs per acre, based on a technique known as the Rational Method. This reflects the fact that most of their natural undeveloped areas are poorly drained. The authority adopted 0.125 cfs per acre as the maximum allowable release rate for detention ponds in their jurisdiction, with a minimum storage capacity of 1.0 acre-feet per acre.

The Fort Bend County Drainage District also adopted a release rate of 0.125 cfs per acre, with minimum detention volume requirements ranging from 0.62 to 0.98 acre-feet/acre.

The City of Houston's maximum allowable release rate can be as high as 2 cfs per acre, with detention volume requirements of 0.2 acre-feet per acre to 0.45 acre-feet per acre, depending on the size of development.

Modeling on the Katy Prairie concluded that natural habitats absorb far more water and thus have far less runoff than detention regulations assume.

While subject to confirmation or change based on enhanced data collection being planned, modeling conducted as part of the Cypress Creek Overflow Study, which was completed by Harris County Flood Control District and the Texas Water Development Board in 2015, found that natural habitats could have an infiltration potential ten times greater than the infiltration potential of commercially or industrially developed lands and approximately two times greater than that of residential land uses with a mix of impervious surfaces and man-made landscaping. The assessment investigated areas in and around the Katy Prairie, a tall grass coastal prairie that once encompassed more than 1,000 square miles (640,000 acres), in what is today northwestern Harris, Waller, and Fort Bend counties. To understand the effect of these habitats on flooding, HCFCD applied a hydrological model to the Addicks watershed. The Hydrologic Modeling System (HEC-HMS), developed by the U.S. Army Corps of Engineers and used by HCFCD, estimated that for natural land cover types with 0% impervious cover, 60% of a 3.38-inch in 24-hour rainfall event and 29% of a 12.17-inch in 24-hour rainfall event would infiltrate soils. Conversely, for land with industrial or commercial land uses and 90% impervious cover, 6% of a 3.38-inch in 24-hour rainfall event and 3% of a 12.17-inch in 24-hour rainfall event would infiltrate soils.

In this case, developing a site from natural conditions to residential increased runoff by 1.79 inches in the 1% event, which is 0.30 acre-feet per acre of impervious cover, and developing that site to commercial or industrial increased runoff by 3.21 inches in the 1% event, which is 0.34 acre-feet per acre of impervious cover. This is the increase in the total amount of water coming off the site. While this is not a straightforward indication of how much detention is required, since detention volume is calculated to limit rate not volume, it is notable that the increase in volume itself exceeds the City of Houston of detention requirements of 0.2 acre-feet per acre. Like all modeling, this data is not perfect, but it raises significant doubt that the current regulations are adequate.

Based on this work, HCFCD adopted more stringent detention regulations for the Cypress Creek Overflow area, based on

*Runoff Behavior in Addicks Reservoir Watershed, Modified from Table D4.1 in Cypress Creek Overflow Study, Appendix D, page 12.**

		50% (2-Year) Rainfall Event					1% (100-Year) Rainfall Event				
Land Use Type	**Impervious Cover**	**Rainfall (in.)**	**Runoff (in.)**	**Runoff (%)**	**Infiltration (in.)**	**Infiltration (%)**	**Rainfall (in.)**	**Runoff (in.)**	**Runoff (%)**	**Infiltration (in.)**	**Infiltration (%)**
Natural Habitat	0%	3.38	1.35	40%	2.03	60%	12.17	8.6	71%	3.57	29%
Residential Housing	50%	3.38	2.37	70%	1.01	30%	12.17	10.39	85%	1.78	15%
Commercial / Industrial	90%	3.38	3.18	94%	0.2	6%	12.17	11.81	97%	0.36	3%

**Based on now out of date numbers, with new numbers released by NOAA Atlas 14.*

“unique hydrologic and hydraulic conditions that exist in the western region of Harris County.” These regulations reflect “in the detention calculations of the higher rate of stormwater storage that is occurring within the upper Cypress Creek watershed under the existing rural and minimally developed conditions.” As noted above, these regulations require retention rather than just detention, limit discharge rates, require ponding to be taken into account, and require larger detention volumes of at least 0.65 or 0.55 acre-feet per acre (depending on modeling method), rather than 0.55 or 0.45 acre-feet per acre under the standard regulations.

This Cypress Creek Overflow Study was one of the first assessments quantifying the relationship between rainfall runoff and natural ecosystems in the greater Houston region. No such studies have been conducted for many of the other ecosystems in the region. There is no reason to conclude that the Katy Prairie is the only natural or agricultural area that behaves differently than the regulations assume. We do not know if other areas of the region also have high rates of natural storage and would need more stringent regulations as well.

Measurements in the Katy Prairie show that natural habitats can absorb large quantities of stormwater in a way that developed landscapes cannot.

The Cypress Creek Overflow Study included field measurements which found higher absorption rates and lower runoff than the model results. HCFCD monitored six sites in the Cypress Creek watershed representing three land cover types: open space, native prairie, and developed land. While the sample size was small, with data collected from five sites, runoff rates for native prairie were significantly lower than those of commercial land uses. For example, a 3.53-inch rainfall event on the Lower Tucker native prairie site resulted in 75% of the rainfall being absorbed by the landscape; a 4.54-inch rainfall event at the developed land use site resulted in 35% of the rainfall being absorbed by the landscape. For smaller events of approximately 0.3-inches of rainfall, native prairie sites saw upwards of 100% absorption of rainfall volume. For similarly sized rainfall events, the developed sites resulted in 41% and 50% absorption of the rainfall volume. This measurement is limited; it was not been over an extended period, on a large scale, or in other habitats. But, like the modeling, it raises significant question whether the current regulations are adequate.

Calibrated HCFCD watershed models indicate pre-development runoff is less than detention regulations estimate.

HCFCD maintains computer models for the major watersheds in Harris County. These models are used for the purpose of designing flood control infrastructure and determining floodplains and are intended to accurately reflect the behavior of the watershed. These models indicate that runoff from undeveloped areas is considerably less than the 2 cfs per acre detention regulations will allow.

For example, the drainage impact study for the 797-acre Bridgelands Phase 2 development in the Cypress Creek watershed, approved by the HCFCD, includes existing conditions models for a large portion of the Cypress Creek watershed, based on the HCFCD model. This particular model was recalibrated after Tropical Storm Allison to better match measured runoff. Many of the subareas in this model shows runoff of around 0.3 cfs per acre:

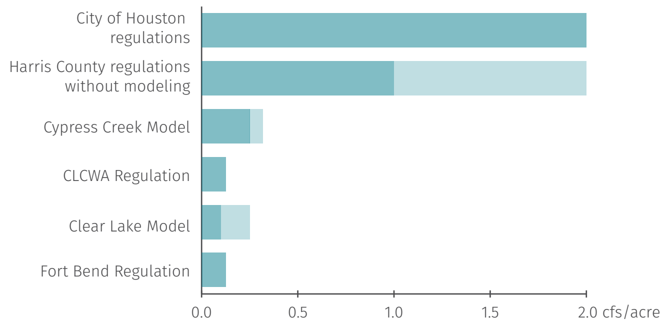
Undeveloped Runoff Rates from Select Subareas

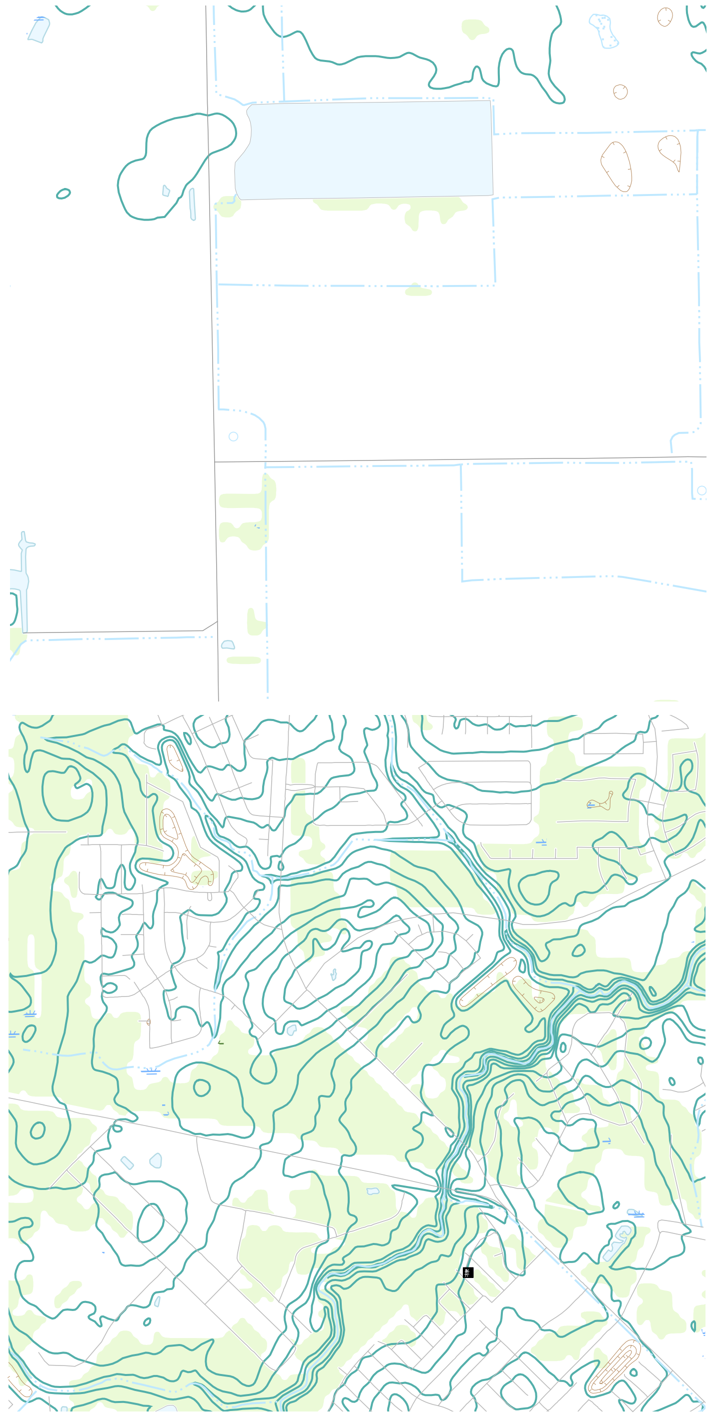
Entity	Runoff Rate (cfs per acre)	Acreage
Clear Creek Subareas		
A100B	0.32	1416ac
A100E	0.37	2368ac
A100H	0.37	2477ac
A100L	0.32	3866ac
On the creek itself		
A100	0.18	10496ac
A100	0.13	20480ac
Hickory Creek Subarea		
HI100A	0.37	2304ac
On the creek itself		
HICK0100	0.18	29696ac
HICK0100	0.36	4928ac
Chigger’s Creek Subarea		
CH100A	0.35	2803ac
Clear Creek		
A100B	0.32	1416ac

These runoff rates are 15% of what is allowed to run off a developed site under the default criteria for City of Houston and may be less than what is modeled with HCFCD methods for larger sites. In larger watersheds, where water from different sites takes different amounts of time to reach a waterway, the overall rate is less than the runoff from individual sites. However, it is highly unlikely that these effects would result in such low watershed runoff rates in relatively small watersheds.

The low runoff rates in some watersheds indicate that the regulatory requirements may not be adequate in all cases.

Allowable Runoff Rates





Topography variation across Harris County. 5 foot contour lines.
Intersection of House Hahl Road and Katy Hockley Road in the Katy Prairie (top) and Tomball near Willow Creek (bottom).
Taken from the National Elevation Dataset, 2010.

Land Cover Across the Region[1]

Note: Watersheds, including Spring Creek, Cypress Creek, Addicks, Barker, Greens, and San Jacinto River, have significant undeveloped areas. In these, with current regulations underestimating pre-development runoff, more development will increase downstream flooding.

Current regulations do not address the variation in soils and vegetation across the county.

The soils, vegetation, and topography of the Houston region vary significantly, from forest to prairie and clay to sand. In their undeveloped condition, different areas, even within the same watershed, have dramatically different runoff characteristics. Even after a site is developed, different soil types make a significant difference; a lawn planted on clay absorbs very little water while a lawn planted on sand absorbs quite a bit. Regulations, though, do not address this variation. Both city and county use a single number for allowable runoff post-detention.

The standardized detention requirements do not address variations between watershed and sites, which can change the rate of runoff by a factor of 10.

The City of Houston detention requirements are based on a prescribed volume of detention per area of land. The site factor that is taken into account is the percentage of impervious cover. There are other factors that affect runoff.

The variation in soil and vegetation types is well understood. In the 1930s, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) developed a method to describe the rainfall-runoff relationship. That method, known as the NRCS Curve Number (CN) has been widely used to describe the amount of precipitation that is converted to direct runoff as a function of retention (the land's capacity to hold water). CN values may vary between 30 and 100, with low CN values representing higher maximum retention and high CN values representing low maximum retention. Sandy soils with good hydrologic condition and forest or wetland vegetation might expect low CN values near 30. Grasslands and wetlands of good hydrologic condition on poorly draining soils with low permeability, such as clay soils, can expect CN values between 35 and 55. Conversely, a pasture with clay soils and poor hydrologic condition can see a CN value of 89.

Runoff is directly dependent on the specific conditions of a site. The amount of runoff does not rely solely on the percentage of impervious cover. As discussed earlier, topography, soil type, and vegetation play a role in how much runoff can infiltrate in the ground and how much can be stored in natural depressions. Runoff from undeveloped sites may vary greatly from the estimated 2 cfs per acre from the City of Houston regulations depending on the site conditions. For example, if 10 inches of rain falls on a park or open space, 3.56 inches would run off from soil type A and 8.16 inches would run off from soil type D. Soil type can cause large differences in the amount of runoff generated from a site. Even in a dense residential area, the difference between runoff from soil types A and D is approximately 2 inches.

Flow of water through Cypress Creek Watershed

Harris County has recognized that some areas require different regulations.

Recently, HCFCD recognized that certain watersheds, such as the Addicks Reservoir watershed, the Barker Reservoir watershed, and the Upper Cypress Creek watershed, which are impacted by flood waters overflowing from Cypress Creek, exhibit drainage features that are somewhat different than the rest of the county, and as such, have implemented Supplemental Guidelines for these watersheds. In general, new developments and infrastructure projects within the specified watersheds are required to:

• Perform impact analyses demonstrating no adverse impacts associated with development of properties or infrastructure projects that are affected by, or contribute to, the overflow of floodwaters from the Cypress Creek watershed to the Addicks Reservoir watershed.

• Dedicate and construct public overflow conveyance facilities.

• Install stormwater runoff volume control (retention volume) for development of properties located within the Addicks Reservoir and Barker Reservoir watersheds, as well as a portion of the upper Cypress Creek watershed upstream of and adjacent to locations where the overflow occurs.

• Use revised Site Runoff Curve equations for detention calculations in the upper Cypress Creek watershed.

• Use revised minimum detention requirements in the upper Cypress Creek watershed.

The updated guidelines for these specific watersheds establish a reduced maximum allowable release rate of about 0.5 cfs – 1 cfs per acre of new development, as compared to the 1 cfs – 2 cfs per acre release rate being used in the rest of the watersheds in Harris County. Also, with the reduced release rate, the minimum detention volume has increased to 0.65 acre-feet per acre (as compared to 0.55 acre-feet) for smaller developments and 0.55 acre-feet (as compared to 0.45 acre-feet) for larger developments. In addition, retention volume (letting water be absorbed or evaporate rather than simply storing it and releasing it later) is now required in these selected watersheds to help mitigate for the increased runoff volume being generated by new development.

These requirements were developed based on the Cypress Creek Overflow Study. No similar studies have been performed in other parts of the county to determine if the natural conditions there require watershed-specific regulations. Such studies would be most relevant in the Spring Creek, Cypress Creek, Addicks, Barker, Greens, and San Jacinto River watersheds that have significant undeveloped areas.

Soil Types Across the Region[2]

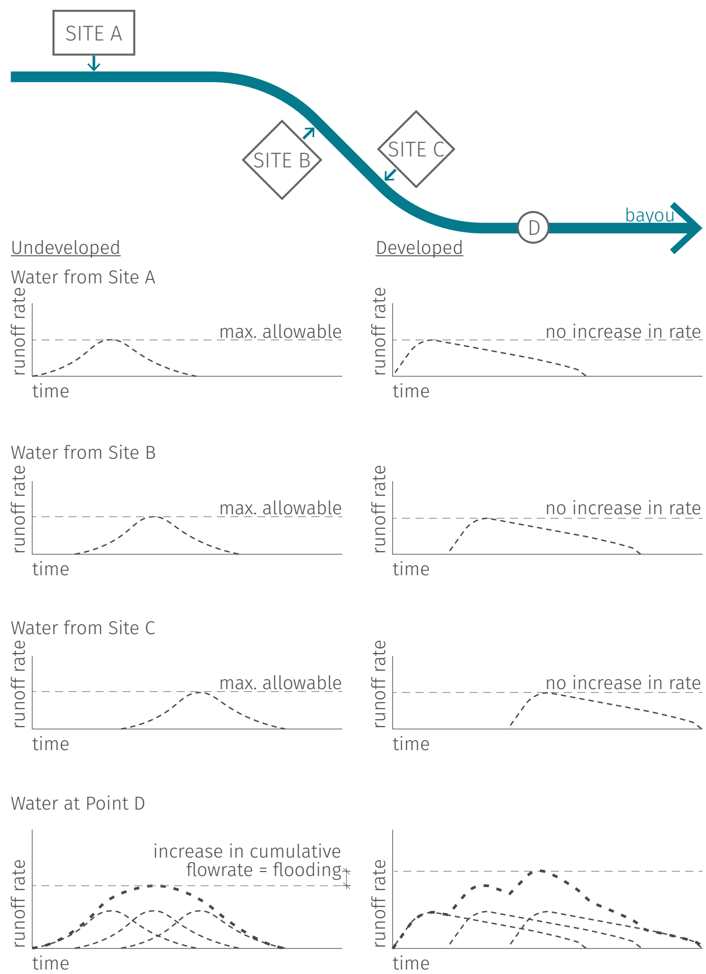
This map reflects considerable variety in the soils within the Houston region.

Current regulations only address one measure of flooding in one kind of storm.
The central premise of all local detention regulations is limiting the rate at which water runs off the site – how many cubic feet drain per second. This addresses one of the major impacts of flooding: the more water flows through a drainage ditch or bayou, the higher the water level. However rate is only one aspect of flooding. Regulations do not limit the total volume of runoff or the time for which high runoff rates are maintained. Further, City of Houston regulations for small sites do not currently address storms other than the 1% AEP design storm.

Detention regulations only address rate, not volume.
In a typical development that meets current regulations, the maximum flow out of the detention ponds meets the regulatory requirements, which in theory matches the maximum flow off the site before development, although this may not be the case as addressed by previous sections of this report. However, rather than the runoff from a developed site briefly reaching that rate and then falling off again, a rate close to the maximum rate is maintained over hours as the detention ponds drain. The total volume running off the site is significantly higher than the pre-development volume.

Higher runoff volume means more water in any reservoir or regional detention pond that is downstream of the site. Addicks and Barker reservoirs, for example, hold water for weeks after an event; the water levels in the reservoirs (and the level of flooding in neighborhoods behind the dams) is determined by the volume of water that flows in from upstream, which regulations do not address. Since detention ponds are typically required to empty within two days, any increase in volume of runoff will end up within the reservoirs well before the reservoirs have emptied.

Higher runoff volume can also increase flow rates in a watershed even if the peak flow rate from each site remains the same. Natural sites generally reach the peak flow rate only briefly before flow drops off again. In a larger watershed, water runoff from upstream takes hours or days to make it downstream. Thus, the runoff from downstream sites will have peaked long before the peak runoff from upstream reaches that point. The maximum flow in the channel is not the sum of the peak runoff rates from each site but rather a significantly smaller number, since the peak flows for different parts of the watershed reach the channel at different times. A detention pond, though, drains at whatever rate the outflow pipe will allow. That peak flow can be sustained for two days as the pond empties. Thus, the sites in the middle of the watershed may still be releasing at peak rate as the runoff from upstream reaches that area. Thus, even if each individual site has no increase in runoff rate, the total flow rate in the bayou, and thus the risk of flooding, has increased. Modeling efforts have demonstrated this; a study in the Little Cypress Creek watershed[3] (Fang et. al, 2010) found that local detention ponds that actually decrease maximum runoff volumes from individual sites by 25% could nevertheless increase flows by 12% downstream.



Cumulative runoff rate from multiple sites.

Detention regulations are not designed to handle multi-day storms.

Detention ponds are not effective once they reach capacity, which happens more quickly when designed to a shorter rainfall duration. The standard of practice is to consider a 24-hour rain event when modeling surface runoff and designing detention; as Austin, San Antonio, Fort Worth, Dallas, and Harris County do. The City of Houston currently requires designing for a minimum of 3-hour rainfall for sites smaller than 200 acres and 6 hours for those larger than 200 acres. Designing detention to hold only three or six hours of rainfall may mean the detention ponds could fill up before the peak of a storm hits.

A natural system can still hold some runoff on day two or three. Most depressions are filled and the infiltration rate is down to a minimum after day one, but natural topography is still slowing everything down and large quantities of water are held as slow-moving overland flow. After development, the only storage is detention ponds, which are likely full after the first day and which will release water quickly.

However, the Houston region gets a variety of storms. While brief and intense 6-12 hour events (like the 2015 Memorial Day and 2016 Tax Day floods) are common, Houston also experiences multi-day rain events, often when tropical systems stall as was the case with Hurricane Harvey and Tropical Storm Allison. The current NOAA 3-day 1% AEP event at Intercontinental Airport is 22.1 inches -- compared to 16.9 inches for a 24-hour storm and 11.2 inches for a 6-hour storm – and there have been several storms along the Texas Gulf Coast that have exceeded these durations and rainfall quantities. Regulations could be written to account for such multi-day events.

Detention regulations are not designed to address smaller rain events.

The City of Houston requires detaining any water in excess of the maximum peak flow during a 1% AEP (100-year) storm event though many areas flood during smaller storm events. (Refer to Fact Sheet 4 – How are floodplains designated? for more information on 1% AEP events.) Smaller rain events are not regulated. Post-development, runoff from rain events smaller than the 1% AEP event increase as well, but will only be detained to the 1% pre-development rate. Thus, the runoff rate after development and detention could increase during smaller events. In smaller but more frequent rain events after development, more runoff may accumulate downstream than before. Thus, a downstream area may not flood more severely due to the new development, but it may flood more often.

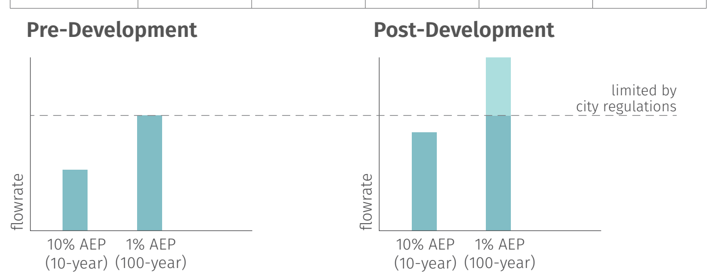
To prevent flow increases in smaller storm events, multiple storm events can be regulated by using multiple opening outlet structures and other design features. The following table shows a comparison of other entities that require detention design for multiple storm sizes. The City of Houston currently requires low level controlled release from detention basins at a rate of 0.5 cfs per acre when detention basin water depth is at 25% of its capacity, but there are no specific requirements for checking the effects of runoff in storms of different sizes.

Detention regulations do not address downstream erosion.

Channels and bayou banks often erode in high flow conditions. The level of erosion is determined not just by the flow rate (and thus the speed and level of the water) but how long that flow rate is maintained. A developed site that keeps the flow rate the same as pre-development conditions, but keeps that flow rate for a much longer period, can have significant downstream erosion impacts. Some areas of the country, such as western Washington State, require a flow duration analysis to be performed so that the release of runoff at any point does not exceed an erodible rate. Requirements such as these may necessitate stored volume of water is released more slowly than existing runoff to prevent any impacts from this additional runoff. HCFCD's inclusion of a 20% design event helps address this.

Size of storm each entity regulates

Entity	Size of storm measured by Return Interval				
	50%	20%	10%	4%	1%
Houston					•
HCFCD	•		•		•
Austin	•		•	•	•
San Antonio		•		•	•



Regulating smaller to the 1% AEP flowrate instead of pre-development conditions sometimes results in increased flooding during smaller events.

The effectiveness of detention varies from the upper to the lower reaches of a watershed.

Regulations could also vary the required detention based on the location of a site within the watershed. Detention is generally less useful in the lower portions of watersheds than in the middle or upper reaches, and it may make sense to not require detention on some site, especially in the lower reaches of a watershed. Such regulations could require detailed studies across all of the county's watersheds that take into account the variety of local conditions.

CONCLUSIONS

The detention and detention regulations adopted from the 1980s forward by the city and the county have dramatically decreased the impact of new development on flooding. Today, the understanding of rainfall and flooding and the tools available to analyze the impact of flooding have significantly improved, which provides an opportunity to create more effective and more targeted regulations.

As this report states, under current detention regulations from the City of Houston and HCFCD, depending on existing site conditions, new development, especially in previously undeveloped areas, can increase downstream flooding. Native prairies and woods-and to some extent agricultural land-absorb several inches of rainfall, and the stormwater that does run off, does so slowly. The grading of sites and installation of storm sewer systems speeds up stormwater runoff, and the shallow roots of typical landscaping do not absorb water the way native prairies do. As a result, the assumed conditions in current detention regulation calculations overestimate pre-development runoff rate and thus underestimate the increase in runoff. Furthermore, the regulations do not limit total runoff volume, which can make a substantial difference in a multi-day rain event. City of Houston regulations do not address smaller storms and thus new development can increase flooding in those frequently occurring events even if it does not increase flooding in the infrequent large storms.

Inadequate detention does not usually affect the residents of new developments, which are generally designed well to minimize flooding in the new homes. Instead, inadequate detention causes new problems downstream for existing neighborhoods.

If current regulations underestimate the detention needed to mitigate new development, continuing development in the upper reaches of many watersheds like Cypress Creek, White Oak Bayou, Greens Bayou, Addicks and Barker reservoirs, Clear Creek, and the San Jacinto River will steadily increase runoff over time. This runoff will increase flooding in existing neighborhoods. It will also reduce the benefits of the hundreds of millions of dollars in new flood control infrastructure. Rather than improving existing flooding, these improved channels and new detention ponds may only be holding the additional water that is coming from upstream development.

The idea of detention regulations is based on a simple concept: new development should not make things worse for downstream development. That idea, widely adopted in this region since the early 1980s, is fundamentally fair. Not requiring new development to fully mitigate its impacts would essentially be a subsidy for that development, reducing the

cost of building but ultimately requiring taxpayers to pay more for new flood mitigation infrastructure and saddling downstream residents with flood-related property damages. This shifts the burden of paying for flood control onto existing taxpayers and increases flood risk for current residents. Since Houston grew outwards from Buffalo Bayou and Galveston Bay, much of the region's new development is upstream from current residents. This can be a significant equity issue as well, since older neighborhoods are more likely to have residents with lower income and have larger minority populations than new developments.

Enhancements to current regulations could reduce future flooding and its impacts on existing neighborhoods by 1) accurately estimating for pre-development conditions that account for all the ways in which development changes runoff, 2) limit volume as well as rate, and 3) account for storms of multiple sizes. Regulations could also vary the required detention based on the location of a site within the watershed. Such regulations could require detailed studies across all of the county's watersheds that take into account the variety of local conditions. Our engineering community already applies this sort of methodology when planning some (but not all) master planned communities, thus appropriate local expertise exists. Our region could be a leader in this regard.

The process to implement such regulations includes:

(1) Increase the default minimum detention requirements set by City of Houston and HCFCD for lots of all sizes to be a more conservative figure.

(2) Allow any developer or property owner with a lot of any size to provide less than the default minimum requirement if they provide an engineering study, based on field observations, that quantifies pre-development runoff.

(3) Install gages, like those used in the Cypress Creek Overflow Study, downstream of a variety of undeveloped sites across the Houston region to collect data on runoff.

(4) Commission studies on the undeveloped portions of all major watersheds in Harris County to determine appropriate detention parameters, taking into account cumulative effects across entire watersheds. These regulations could vary across a watershed based on site conditions and the location within the watershed, but they should be coordinated across multiple jurisdictions so that the requirements do not arbitrarily change at a city limit line.

(5) Based on these studies, set specific regulations for watersheds or part of watersheds.

(6) Require the evaluation of cumulative effects across entire watersheds.

(7) Require evaluation of 3-, 5-, or 7-day events

While there is not enough information to quantify the degree to which current regulations fall short of mitigating flooding, there is sufficient data to indicate that, in some cases, they do, and that warrants this further investigation.

CITATIONS

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2 Esri, HERE, DeLorme, increment P Corp., NPS, NRCan, Ordnance Survey, © OpenStreetMap contributors, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community. http://esri.maps.arcgis.com/apps/View/index.html?appid=cdc49bd63ea54dd2977f3f2853e07fff

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